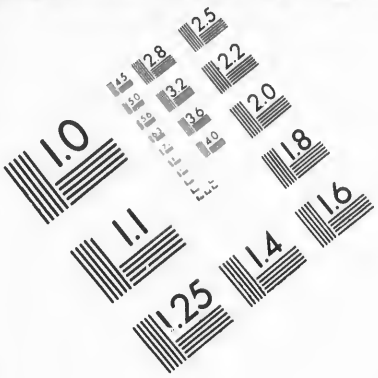

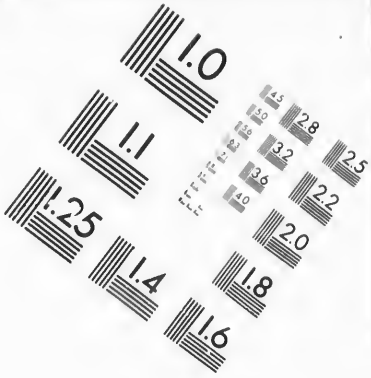

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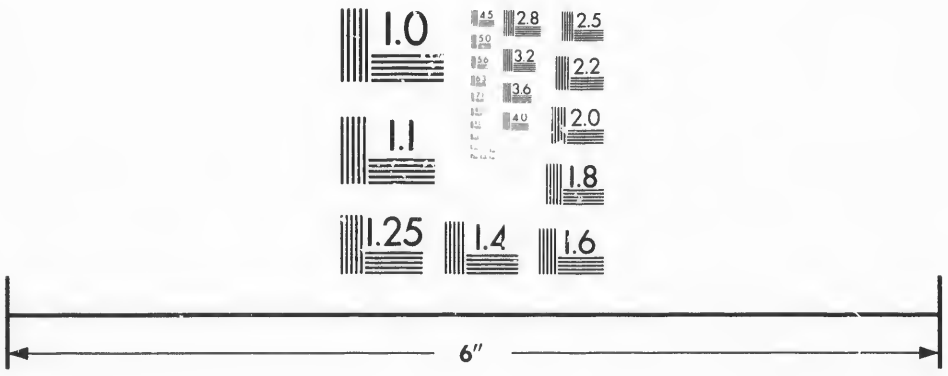

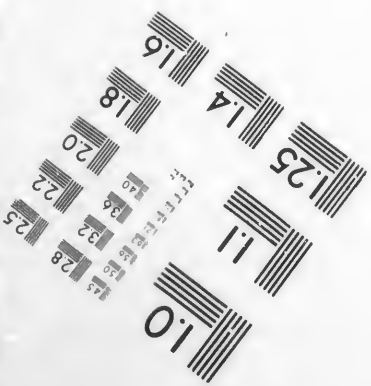

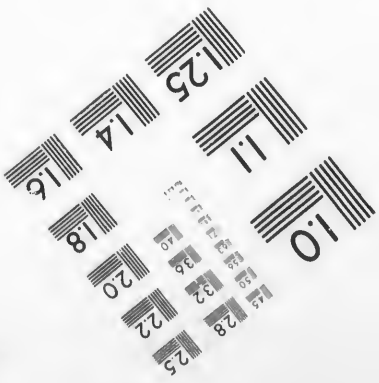

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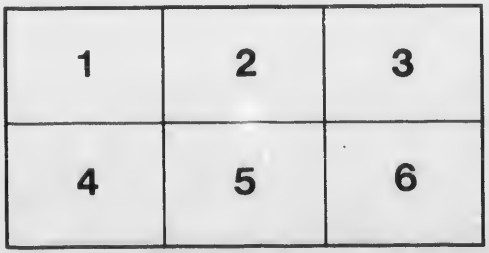

87

FOR PRIVATE CIRCULATION.

A PLAN

FOR THE

IMPROVEMENT OF NAVIGATION

AND THE

PREVENTION OF FLOODS

IN THE

MISSISSIPPI RIVER.

BY GEO. H. HENSHAW, C. E.

Montreal:
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aw no 2499

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A PLAN for the Improvement of Navigation and the Prevention of Floods in the Mississippi River.

BY GEO. H. HENSHAW, C. E.

THE problem of the prevention of those disastrous floods which from time to time devastate the borders of the Mississippi river, though of vast interest to the United States at large, not to mention its still more vital importance to the States immediately concerned, not only remains unsettled, but continues to be the subject of warm debate; too often, as is usually the case in protracted discussions, degenerating, from the calm atmosphere of scientific discussion, into the heat of dogmatic assertion, and even at times into personalities.

Plans already proposed.

Two rival modes of remedying the evil have hitherto occupied the attention of the public, both based on hypotheses, which, if not erroneous, are, at least, as we shall see, incomplete and inadequate. One of them proposes to draw off the surplus water; the other to reduce outlets and narrow the river, and so employ its full volume to scour out the bottom.

The outlet plan.

The first plan advocates the opening up of outlets to carry off the surplus water, evidently on the simple hypothesis that, if you draw off water from a basin you lower its level. Now this, if we omit all other conditions, is so undoubtedly true as to need no demonstration. But a hypothesis, to be received as complete, must be subjected to three tests, and these, as regards explanation of phenomena, we find put before us in a clear and concise form by Professor Huxley, thus: "We must, in the first place, be prepared to prove that the supposed causes of the phenomena exist in nature; that they are what the logicians call *vera causæ*—true causes; in the next place, we should be prepared to show that the assumed causes of the phenomena are competent to produce such phenomena as those which we wish to explain by them; and

in the last place, we ought to be able to show that no other known causes are competent to produce these phenomena." In the problem we are now considering, however, two successive hypotheses are needed, each of which must be subjected to similar tests, the first being to solve the question: what are the causes of floods? and the second to solve the quesion: what will prevent them?

Reasoning from the position taken by the advocates of the outlet system, we may assume that their hypothesis of cause is as simple as that of their remedy, namely: that floods are caused by the influx of an unusual quantity of water. Now let us see how this will stand the tests. The first it certainly does; it is a true cause, if not a sole one. The second gives a doubtful result; indeed, as we shall see later on, more than doubtful; for the present it is enough to note that this cause alone can not always be competent to produce a flood, since we have only to suppose a sufficient deepening of the river to prevent it. The third test quite destroys the hypothesis, since it is only necessary to suppose a sufficient quantity of alluvium deposited on the bottom by an ordinary freshet, in order to account for an extraordinary rise. We find, therefore, that other causes than that assumed may produce floods.

The first hypothesis having failed, the second might be supposed to fail also, but this does not absolutely follow; a remedy may prove effective even if we have not succeeded in penetrating to the real causes of the phenomenon; it must therefore be tested on its own merits. The first question then is: is the remedy one really able to remove the difficulty? To this we must answer yes, at least temporarily. The next question is: is the remedy calculated to afford a permanent improvement, such as is desired? To this question we must give a negative reply, for the following reasons: In the first place no proof is offered, nor, in my opinion, can be offered, that it will have any beneficial effect on the river in the way of preventing deposit of sediment; in the second place, even the negative ground taken, that the loss of velocity caused by the outlet will not result in increased deposits, is not only not proved, but its oppo-

nents seem by far to have the best of the argument; lastly, it is universally admitted, increase or no increase, that the bottom of the Mississipi is continually shifting and changing, so that obstructions are, from the very nature of things, liable to occur to such a degree as of themselves to produce floods at high water; and it is for this reason that supporters of this system are compelled to call, periodically, to their assistance the merely mechanical labor of dredging, the extent and frequency of which being unknown, and well nigh unknowable quantities. The last question is: is the proposed system really the best that we can reasonably hope to devise? for it would be obviously unfair, under present conditions of human imperfection, to demand proof that it is the best that *can* be devised. This question I also answer in the negative, for reasons which it is the chief purpose of this paper to set forth.

Plan of narrowing.

The second plan advocates completing the levees, conserving inlets, reducing outlets, and narrowing wide portions of the river; all for the purpose of using the entire volume in scouring out the bottom of the river, and thus sinking the level of its surface.

Its hypothesis of cause is this: that water being charged with sediment in proportion to its velocity, therefore, when the velocity is diminished, deposit occurs, and this deposit, by raising the bottom, is the cause of overflow. In considering this hypothesis, much depends on the meaning we attach to the somewhat obscure word "charged," to which we will refer later on; if, however, we assume, for the present, the meaning to be, in general terms, that sediment is *transported* in quantities proportionate to the velocity of the stream, then we may readily admit that the hypothesis stands the first test. The cause given is a true one, though, as we shall see, not completely stated nor quite understood in its most important bearing. But in admitting the success of the first test, we seem, in this case, to admit the success of both the others, since the cause must not only be competent to produce floods, but must be the sole cause competent to produce them, if we except the suppositious case of such a body of water being introduced, as to cause overflow without the aid of shoal deposits. No case of

this kind has been shown to have ever happened, and the onus of proof, undoubtedly, rests on its advocates, in face of the facts, admitted on all hands, of the great movements of sediment deposits continually going on at the bottom of the river. I think, then, that we may consider the hypothesis of cause fairly sustained.

The success of the first hypothesis, however, no more proves the truth of the second, than, as we have seen, its failure invalidates it; we must ask then, first: is the system of preserving inlets, reducing outlets, and narrowing wide parts of the river competent to produce the wished-for effect? And in considering this question we must remember that it is the Mississippi river we are dealing with, and not an ordinary stream; a river, in short, of great width, and of immense differences of volume between high and low water. The most favorable answer, therefore, I can give to the question is: not proven.

Enclosing, as the proposed plan does, within its terms, all the natural powers available for producing the deepening of the river, it is obvious that an affirmative answer would carry the second test with it, namely: Would the effect be permanent? my reasons must therefore be comprehensive of both.

That a heavy scour of the bottom would occur, we cannot doubt, but are we equally sure that it would be regular? or, that in a stream of such width and volume, a corresponding deposition would not take place, tending to precipitate the very catastrophe it is designed to avoid? Is not this very effect the more likely to happen, when we consider that, practically, all the material scoured from the bottom, as well as that brought in by tributaries, will have to be carried the whole distance to the sea, through the navigable channel itself? And finally, is it not to be expected, in so wide a stream, that variations in the currents of low water, will produce new obstructions, offering recurrent resistance to the high water?

If we could assume that beneath the present bed of the Mississippi there exists an original smooth impenetrable trough which has since been filled with sediment, we would have little difficulty in reconciling the law of least resistance with the idea that the area of the trough might at last be swept clear by the means proposed, but

that is impossible; inexorable law must continue, eternally, to dig out holes in the softest spots, and to demand a passage at the weakest places.

The first and second tests, then, fail, or, to put it in the mildest form, give extremely doubtful results. We go on now to the third test: Is the plan proposed, the best that we can reasonably hope to devise?

To this question I answer, no: the reasons for which, as I hinted in giving a similar reply in the case of the first scheme, I shall now proceed more particularly to give, with a few preliminary remarks.

Transportation of sediment.

In reviewing the arguments put forth by the advocates of the rival schemes we have just noticed, one is at once struck by the seeming fact that the chief issue of the controversy centres in the question: what is the cause of the precipitation of sediment? one side affirming that water is charged with it in proportion to its velocity, and that deposit takes place in proportion as velocity is diminished: the other maintaining that diminution of velocity will not cause deposit, because the sediment is rolled along the bottom and not carried in suspension. Now, to my mind, it seems that the point in dispute has very little to do with the real solution of the difficulty, and I cannot help thinking that the very heat with which it has been discussed has prevented the very able supporters of both systems from advancing to the discovery of the true key, which lies in a very different direction; nevertheless, enough importance has been attached to it to justify a short analysis of its merits.

The term "charged."

The term "charged," so much used in reference to the association of sediment with water, is very misleading, though it is perhaps the most convenient to use. Of course everybody knows that a stream cannot be charged, in any definite way, with sediment, as it might be with gases or soluble matters. If I understand the arguments rightly, the meaning on one side is, that the heavier sediments, which are the cause of obstructions, are rolled along the bottom, (not carried in suspension), until an equilibrium is reached. At this point they rest and may be dredged away, where they interfere with navigation, while the lighter could be largely carried off by outlets and so relieve the main river. On the other side it is

held that sediment of all kinds is carried by suspension, being taken up or dropped in proportion to the stream's velocity. Now, assuming the point to be a vital one, it is easy to see the importance of its bearing upon the utility of the rival schemes proposed, but it seems never to have occurred to either side, that the problem may be much less simple than they have supposed, nor that possibly both views may be confirmed by employing different sets of observations. They have, as it were, arrived from opposite directions, at the circumference of a circle, and then stopped instead of proceeding to a junction at the centre; in other words, each has fancied himself at the heart of the matter, when, in reality, both stand only at the beginning of its solution.

Key to the problem.

The real key to the solution of the problem lies, not in any proof of the amount or proportion of sediment carried or deposited, but in the answer to the question: in what lines is the great body of obstructive sediment deposited?

The general proposition that water is charged with sediment in proportion to velocity gives no answer, but will do to start from. Now, velocity in itself cannot charge. It is its effects, first upon the stream, and next, through it, upon its bed, that causes the charging; that is to say: the intermolecular movements of the water, and the still greater agitations caused by obstructions at the bottom and sides—both governed by the law of motion in lines of least resistance—create currents, in every direction, of incalculable multiplicity, variety and power, along which are carried the particles of sediment, that have been scoured from the bed, until the whole volume of the stream is more or less pervaded by them. Hence we see that the charging of the water is due, not to the *onward* velocity of the stream, but to the vertical and lateral movements of the sub-currents accompanying it. Whatever credit, then, we may give to the abstract proposition, that reduction in velocity will cause deposit, we find that it cannot be practically applied in the broad sense claimed, for, as the obstructing masses are infinitely various and ever varying, so must the friction, amount of scour, and retardation, resulting in these swirls and eddies, also vary in degree; and thus, a constant lifting

and dropping of the heavier particles—almost to be described as "rolling"—must take place, those only which are light enough to be borne about by the finer molecular currents, being carried for any great distance without resting on the way. I may here remark that a careful consideration of these facts will, I think, convince the reader that the rival theories have now been brought so close together as to amount to but little more than a difference in forms of expression. There is no paradox in the assumption, that amongst the multiplicity of move ments going on throughout the length and breadth of such a river as the Mississippi, both the phenomenon of rolling sediment, and that of its being whirled up to the surface, must be frequently observable.

New plan proposed.

The plan I have now to propose will depend for its success upon the answer given to the question which I have called, the real key to the problem, namely: in what lines is the great body of obstructive sediment deposited? and also, on the adaptability of the means I propose to use, to obtain the desired end.

Facts and theories relied on.

The amount of scouring force, or friction, on the bottom of a stream is measured by the retardation of the stream's velocity; that is, by the difference between the speed at top and at bottom; varying of course in relation to its specific velocity and depth.

Increased local friction results both from elevations and depressions at the bottom; and, as a consequence of these, the volume of the current being checked by the vertical movements of swirls and eddies, more or less local rise of surface naturally occurs.

As all bodies move in the directions which offer the least resistance, and as the surface current of a stream encounters fewer obstacles to its onward progress, than that which flows along the bottom, a divergence in the direction of these currents is to be expected; but, as each would react upon and influence the other, we may practically assume the observed centre of the surface current to be the average line of least resistance for the whole volume.

Again, as weaker forces are more easily deflected by obstacles than stronger, it is evident that this observed line of current will, at low water, pursue a more tortuous

course than at high water; hence, at high water the centre line of the current will traverse, at greater or less angles, the low water line.

We have here, then, two great and varying forces alternately affecting the river bottom, and we readily see that the low water must have most influence in determining the course of the deep water channel, and the high water, the form of the shores. The effect of each, however, is greatly modified by the other, for, the centre line of the high water, crossing as it does the low water line more or less diagonally, must in some degree become deflected, and so produce on the contour of the shores a certain tendency to follow the curvatures of the deep, or low water, channel, while on the other hand, the overpowering volume of the high water, being only partially deflected, must, to a greater or less extent, cut away the bounds of the low water channel, and originate other channels, which in their turn will be influenced or followed by the subsequent low water; all these movements resulting in incessant changes over the bottom area, and in obstructions the extent of which cannot be predicted. What, so far, I have endeavoured—perhaps with unnecessary prolixity—to show, is, that the high and low water forces are essentially antagonistic, their natural conditions being such as to preclude the possibility of their ever acting in a common direction, except under artificial control. For the sake of clearness I have simply considered the effects of high and low water currents as on a single channelway, but when we reflect upon the great width of the Mississippi river, and the many channels, shoals, and islands spread over its bed, we cannot fail to be still more impressed with the impossibility of any *natural* harmony between those currents ever taking place.

Influence of bottom on the rise of the surface.

If we divide the stream into two layers by a horizontal line, or plane, drawn just above the summits of the bottom irregularities, we shall at once recognize the two causes that produce retardation in the flow of the lower stratum, especially in high water, namely: its direct friction on the bottom, and its inability, independent of this, to overtake the upper stratum, from being obliged to take a more circuitous course. Hence, as the same volume must pass a given point in a given time, the surface must

rise enough to accommodate it. Also the retardation of the upper stratum will be directly as the obstructive force exerted by upward and lateral currents projected from the bottom. As a rule, the surface of a stream, being least obstructed will move the fastest, but cases do occur, especially when a deep narrow channel is flanked by shallows, or when a strong lateral sub-current enters the channel, in which the swiftest part of the current will be found below the surface: such cases are however rare and local in character, and are, therefore, only to be considered as among the myriad phenomena produced under the varied conditions of the bottom The point is not of much consequence, but I do not wish to omit anything relating to the subject, because my system depends, at its outset, upon the truth of the proposition, that the existing conditions of the bottom of such a stream as the Mississippi are sufficient to account for great variations in its surface level, without necessarily introducing additional volumes, either of water or sediment, though of course these are among the immediate but secondary causes of floods.

A normal standard of volume.

Taking a map of the river, on a sufficient scale, and laying down upon it the centre lines of the current, at high and low water, we find, as I have before remarked, that they cross each other at various intervals and angles. Here would seem to be indicated a simple and accurate method of determining the relative tendency to abnormal elevation of surface, at any point of the river, since, at their points of crossing, the two forces would be in conjunction; but, unfortunately, from the instability of the bottom, even these points are continually changing, so that we shall scarcely be able to record their phenomena before new combinations will have begun of equally uncertain stability; besides, if we succeed in overcoming this difficulty, we cannot yet be quite sure that the surface height will prove normal, because the entire scour due to the then existing conditions may not have been completed at the time of observation.

These objections, however, go to prove that a standard of volume based on cross sections taken at such points, though by no [illegible]s accurate, would have its errors always on the [illegible] side, and would therefore afford a

sound practical basis on which to establish the dimensions of the trough of an improved waterway.

Conclusions summarized.

The results of my arguments, so far, may be summed up in the following conclusions.

1st. The occurrence of abnormal floods in the Mississippi river is due to extraordinary accumulations of sediment, near the points affected, principally during the preceding low water and rising season.

2nd. These extraordinary accumulations are merely maximum developments of ordinary accumulations, continually formed, changed or dispersed, by the alternately and irregularly varying currents of high and low water.

3rd. That the greater the divergences in direction between these currents, the greater the disturbance of the bottom will be, and the greater the liability to excessive local accumulations and consequent overflow of the river banks.

4th. That when these currents coincide, no abnormal rise will occur; the tendency being the other way.

5th. That if effective means can be devised, without lessening the waterway, to produce a permanently concurrent direction to these currents, the result will be: the cessation of all abnormal elevations of surface and complete security to the levees, even to the possible extent, in some places, of making them no longer necessary.

Cause hypothesis tested.

Though, as I have said, a cure may possibly be a good one, even when the cause of the evil is not fully apprehended, yet, unquestionably, a proved hypothesis of cause is essential to a satisfactory demonstration of the truth of its claims; I therefore conclude these preliminary arguments, by subjecting my cause hypothesis to the three tests already applied to the others. I re-state it thus. The cause of floods is to be found in irregularities formed in the bed of the stream, which, in turn, are due to non-coincidence in the currents of high and low water. In proof of this hypothesis, I submit that I have shown: first, that the cause is a true one; second, that it is competent of itself to produce the phenomenon; third, that no other cause has been shown to be independently competent; not excessive inflow from tributaries, because floods may occur, and may reasonably be expected to

occur, without it; not fresh deposits of sediment (namely those caused by reductions in velocity) because floods can result, and may reasonably be expected to result, from accidentally large, local accumulations produced during the successive re-arrangements of the sediment of which the river bed is already composed.*

The plan.

As is to be inferred from the preceding arguments, the system I propose to adopt for the prevention of floods in the Mississippi, is simply one intended to produce, by artificial means, a coincidence of line in the currents of high and low water, and so cause the scour, no matter what the changes in velocity or volume may be, to act continuously along chosen and permanent lines. If this can be successfully accomplished, I hold it to be self-evident, from the very nature of things, that the desired result must ensue.

I maintain that this result cannot be obtained by extending the levees or by narrowing the river, at least in the commonly understood way, for, if my previous arguments have any weight, it must be plain that any narrowing capable of producing any permanence in the low water channels, must so contract the waterway as to increase the tendency to floods at high water, the danger being of course all the greater when the inflow from tributaries is unusual.

In the plan I propose, narrowing to a large extent will be produced from the conversion of waste areas into reservoirs for the deposit of sediment, but it ignores entirely all questions of creating outlets or closing tributaries as in any way needful to its success. It takes things just as they are, preserving existing conditions when desirable, and removing or modifying them when not; for it claims to be able not only permanently to fix channels already in existence, but also to alter their courses in any direction that may reasonably be required.

General description.

I do not propose in this paper to enter much into the details of the work. They are contained in a small un-

* It will be understood that the effect of fresh deposits is ignored, only in order to show the possibility of overflow occurring independently of them, see report on the remarkable flood on the Missouri river in the Spring of 1881, in Appendix H to the Report of the Mississippi river Commission, dated 25th Nov., 1881.

published work, written by me in competition for the prize of 1881, offered by the King of the Belgians, on the subject of improvement to harbors, rivers, &c., on sandy coasts, the award on which has not yet been announced. It will be enough, for the present, to give such a general outline as will enable the reader to form a judgment as to the practicability of the system proposed.

Preliminary work.

The first thing to be done would be to map out the principal channel lines, as they are indicated by the surface flow at both high and low water, over the portion of the river to be operated upon. Cross sections would then be taken at their points of intersection, and normal areas deduced from them according to the relative velocities. These normal areas, though by no means mathematically exact, can, as we have seen, only err on the safe side, and, as the approximation is close enough, nothing more is needed.

The next process is to lay down upon the map such channels as are best adapted to the purposes of commerce, taking care, on economical grounds, to follow as nearly as may be the courses of the existing channels.

Favorable points, according to the best judgment of the engineer, are then to be selected along the river, at each of which cross sections for construction are to be taken, and on the diagrams of these, the normal area for each will be laid down, being distributed proportionally, according as one or more channels are crossed.

Construction.

From both shores, at these places, to the nearest edge of the proposed channels, and between them when there are more than one, a continuous line of vertical, and, as a rule, submerged, screens will be run, either at right angles to the current, or slightly inclined with it, that is downwards.

The screens will be woven with as wide meshes as possible, consistent with their object, which is to offer as little resistance as is compatible with checking the current enough to throw the force of the scour into the channels, and, at the same time, afford shelter between them to the sediment so excavated.

The height of the screens will vary according to circumstances, but one feature in regard to this must in all cases be strictly observed, which is, that from certain

points, laid down upon each diagram of construction, to the edges of the channels, the height shall gradually diminish to nothing, beyond which the base of the screen will project at least from ten to twenty feet in the form of a flap or mat, so weighted as to follow the side the channel as it becomes undermined by slope of the current.

As the excavation of the new channel proceeds, intermediate screens may be introduced wherever they are found to be useful, and when the required depth and dimensions have been attained, an additional improvement may be added if desired, by projecting the mats still further in order to bring the deepest part of the channel to the centre of its trough.

Of course, during construction, dredging will be required wherever the bottom is found to be hard enough to resist scour.

It will at once be seen that this system is entirely independent of any opening or closing of outlets. Those existing, in common with all unnecessary outspreading of the river, will be taken advantage of to get rid of sediment, and thus avoid carrying it all out to sea, and that is all. We see, too, that no deposit due to minor variations in velocity, will take place in the channels, because the scour, whether strong or weak, is continually at work along the same lines. Lastly, it must be equally plain that the adoption of this system is unattended with risk, since the placing and dimensions of the screens can easily be regulated, from the outset, on a scale of absolute security.

Concluding tests applied.

As with the other systems noticed, I conclude by applying the same three tests, but as these must be left to the judgment of the enlightened reader, I simply submit that I have shown: first, that the remedy is one really able to remove the difficulty; second, that the remedy is calculated to afford a permanent improvement such as is required; and finally, that the scheme is really the best that we can reasonably hope—in its main features—to devise.

Alternate Plan II.—Discharging sewage at Outfall "A," storm water at Outfall "B," and sewage and storm water at Outfall "F."

Western Sewage Interceptor, Outfall "A"	$ 18,423
Western Main Sewer, Outfall "A"	220,006
Eastern Main Sewer, Outfall "F"	179,606
	$418,035
Relief sewers, as before	44,415
	$462,450

Alternate Plan III.—Discharging storm water at Outfall "B" and sewage and storm water at Outfalls "C" and "D,"

Western Main Sewer, Outfall "B"	$220,006
Pumping Machinery, etc	22,500
Force Main and Special Sewer on Slater street	26,548
Eastern Main Sewer, Outfall "D"	148,171
	$417,225
Relief Sewers, as before	44,415
	$461,640

N. B.—No estimate of the annual cost of pumping is given.

Alternate Plan IV.—Discharging storm water at Outfall "B" and into Rideau River and nearly all the sewage at Outfall "F."

Western Main Sewer to Outfall "B"	$220,006
Pumping Machinery, &c	22,500
Force main and Special Sewer on Slater street	26,548
Sewage Interceptor on St. Patrick street	26,415
Eastern Main Sewer to Outfall "F"	158,253
	$453,722
Relief sewers, as before	44,415
	$498,137

N. B.—No estimate of the annual cost of pumping is given.